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PERFORMANCE COMPARISON OF FLYASH AND WOLLASTONITE MICRO-FIBER IN OBTAINING SELF COMPACTING CONCRETE MIXES

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ABSTRACT

Present study aims to find out the role of flyash and Wollastonite micro-fiber in obtaining cheap self compacting concrete for pavements. Workability tests (Abrams flow, V Funnel and J Ring test) have been performed which find out the flow, passability and segregation resistance of trial mixes. Load transfer efficiency test has also been performed with successful mixes on a pavement prototype. It was observed, that both flyash and wollstonite micro-fiber when used alone can't yield self compaction, but with microsilica content upto 5% they do so, provided their content is lesser than 20% each, respectively. Wollastonite reinforced concrete has two times better load transfer efficiency with respect to normal concrete.

Key words: flow, micro-fiber, passability, pozzolan, segregation resistance.

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1. INTRODUCTION

Fibers introduction into the concrete was never thought of for a self compacting one because the inherent nature of fibers makes the flow of concrete apparently impossible. But the improvement in flexural strength to higher degree, as well as compressive strength to a smaller degree (1, 2, 3, 4, 5, 6) stressed their use in concrete pavements and structures requiring high flexural strength. But the problem in case of rigid pavements was shrinkage at joints which made it necessary to expedite the construction work so that construction joints could be reduced and whole pavement is cast monolithically with only contraction joints and possible breaks at expansion joints. The feasible solution is the use of self compacting concrete which contain fibers (7, 8, 9, 10). Ordinary fibers can't be used in rigid pavements because they reduce the self compacting ability of concrete (11). Hence it was decided to use micro-fibers which have their aspect ratio ≤ 30μ. Though, the literature proves that they are not so much effective in increasing flexural strength of concrete, as macro fibers do (12, 13, 14), but still a marginal increase in flexural strength, improved load transfer efficiency on

account of rich concrete, and hence can increase the fatigue life of pavement quality concrete to a large scale. Flyash, along with micro silica has been successfully utilized in past for obtaining self compacting concrete (15, 16, 17). In order to check the use of micro-fibers; specifically Wollastonite micro-fibers in present study, the strength and performance of these micro-fibers reinforced concrete in combination with micro silica was compared with those of flyash-micro silica admixed self compacting concrete. Wollastonite micro-fibers has been found to effect the matrix pore structure and enhance the ductility, compressive strength as well as flexural strength of concrete (18).

2. MATERIALS AND METHODS

2.1. Materials Used

Ordinary Portland cement (OPC) 43 grade conforming to Indian standard code IS 8112-1995 was used. It showed retention of 3% on 45 micron sieve. Wollastonite micro-fiber (WMF) having average length of 0.03mm, diameter 1.82μ and thus an aspect ratio of 16.5, obtained from Wolkem India Limited was used. It showed no retention on 45μ sieve. Flyash supplied by National Thermal Power Corporation (NTPC) Ghaziabad was used. It showed approximately 15% retention on 45 micron sieve. Micro silica was supplied by Elkem India. Sand used for the study was obtained locally from Haridwar. Coarse aggregates of maximum size 20 mm were obtained from a local quarry in Haridwar.

2.2. Physical and Chemical Analysis of Materials

Particle size analysis was performed by using Ankersmid laser based analyzer. Figure 1 clearly illustrates that microsilica is finest among all considered powdery materials followed by WMF, fly ash and cement respectively. The largest fraction found for microsilica, OPC, flyash and WMF are 0.145, 20.055, 25.705 and 1.830 microns respectively. Microsilica used in the present work comprised more than 50 percent of particle size in the range of 0.087-.05 microns and 9.639 microns for flyash. This interpretation clearly infers that WMF used was median size to both microsilica and OPC and hence, an excellent interlocking within these particles is anticipated physically. It is also clearly depicted that OPC used for the study, exhibits particle sizes comparable to flyash as revealed by the presence of secondary peak in Figure 1. Peak patterns analysis suggests that fly ash and OPC have nearly same size range but from the prolonged post peak profile of fly ash, it is learnt that there are numerous fraction of flyash those are even larger in size than OPC particles.

Surface area is an important parameter which decides the reactivity and water adsorption tendency of a given volume of material. Table 1 provides the results obtained from Blaine's air permeability test on cement, and BET permeability test on WMF, flyash and microsilica. The results prove that microsilica is the finest among all, followed by WMF, flyash and OPC respectively. If one compares the degree of fineness of microsilica, WMF and fly ash with OPC, they are in the order of 60, 2.8 and 1.3 times finer than OPC respectively.

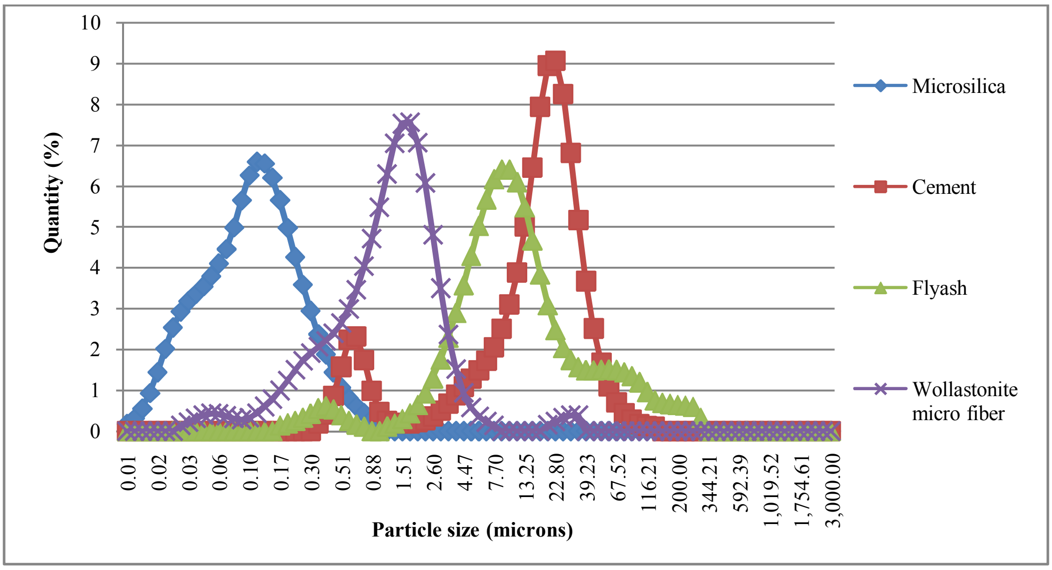

Figure 1 Percentage sizes of various particles

Table 1 Specific Surfaces and Specific Gravity of Materials Used in the Study

Material	Specific surface (sq. m/Kg)	Specific Gravity	Percentage of oxides					
			SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	CaO
OPC	298	3.15	20.2	5.2	3	1.51	2.2	62.9
WMF	827	2.9	48	1.4	0.6	0.2	-	45.9
Flyash	380	2.52	35	26	8.7	5	3	15.3
Microsilica	18000	2.05	92.9	0.9	0.72	0.57	0.16	1.4

Table 1 also shows the specific gravity of cementitious materials, tested using Le Chatelier flask. The results clearly show, that Microsilica offers the lowest value of specific gravity followed by fly ash, Wollastonite micro-fiber and OPC respectively. The specific gravity of admixtures affects the flowability of fresh concrete, along with their viscosity in the paste form. Hence, it could be said that mixes prepared with microsilica would have tendency to achieve better flow, followed by flyash, WMF and plain OPC respectively. Table 1 shows the quantitative results of the amount of oxides present in cement and other admixtures, as has been found through X ray fluorescence spectrometer test when conducted in accordance with IS: 12803.

Flyash contains least percentage of lime and least silica and highest alumina whereas WMF has largest percentage of lime. Microsilica has largest amount of silica. This suggests that initial hydration products (CSH and CH) would be maximum in WMF and flyash followed by microsilica. There size is smaller than OPC so initial hydration rate could be higher (this also depends on their mineral nature i.e. crystalline, glassy or amorphous). Since WMF is inert crystalline in nature, therefore flyash would have nearly same hydration rate as WMF. Though microsilica induces secondary hydration, but since its size is very small and its mineral nature is very reactive (amorphous), therefore it starts secondary hydration very early, at the same time when the initial hydration of flyash and WMF is going on.

2.3. Blended Cement Proportions

The testing program aimed at sequentially finding out the ambiguities related with the use of admixtures and Wollastonite micro-fiber in self compacting concrete. For this one control mix and 45 cement substituted mixes were prepared. The mixes were classified into binary

and ternary. Binary mixes were made by substituting cement with Flyash and Wollastonite (up to 30% replacement of cement with each respectively), in intervals of 10%. For ternary combinations, the mixes were prepared such that Wollastonite and Flyash had same replacement levels and Microsilica was added maximally up to 10% in addition for each mix, at intervals of 2.5% respectively. Then testing was performed on 12 ternary mixes of C-F-S as well as C-W-S.

2.4. Mix Designation and Testing of Concrete Specimens

A control concrete mix was developed in accordance with Indian Roads Congress specification-IRC 44 for a flexural strength of 45 Kg/sq. cm. Flow trials were conducted to achieve SCC by changing the binder content of the control concrete mix (by admixing); then correspondingly changing the fine aggregate to coarse aggregate ratio along with superplasticizer content at a constant water to cementitious material ratio of 0.37. Superplasticizer was added to fulfil the water demand for creating self-compacting conditions. Like control concrete, SCC testing was performed in two forms: fresh and dry. In the fresh state, Abrams flow, V funnel, J ring, probe ring tests were conducted on the SCC trial mixes, whereas control concrete was subjected to only Abrams flow test. Concrete volume of 6 litres was used for Abrams flow test and J ring test, whereas 12 litres of concrete volume was used for V funnel test. Probe ring test was conducted by pouring concrete in cylindrical moulds (150ɸ×300mm). Finally the best cost effective mix showing good workability was tested for its performance with a constructed prototype having 6 ton of concrete (DLC 100mm+ PQC 300mm), and contained a contraction joint, with dowel bars of 38 mm for load transference. The panel size is 1800×1800×300 mm^3, dowel bars of ɸ 35mm and 500mm length were embedded and a dry lean concrete (DLC) layer of 100 mm thickness was sandwiched between PQC slab and properly compacted subgrade layer. Deflections at top of the slab fiber were observed for normal non-rehabilitated PQC (NRP), normal rehabilitated PQC (NCRP) and PQC rehabilitated with microfiber reinforced SCC (FRSCCRP).Sufficient numbers of dial gauges (D.G.) were employed for measuring the deflections at the top of the PQC slab under different loading conditions. The details of loading conditions and deflections measured at different points are presented in Figure 2. The loading was applied by means of circular bearing plate made of steel having 25.4 mm thickness in accordance with IS: 9412.

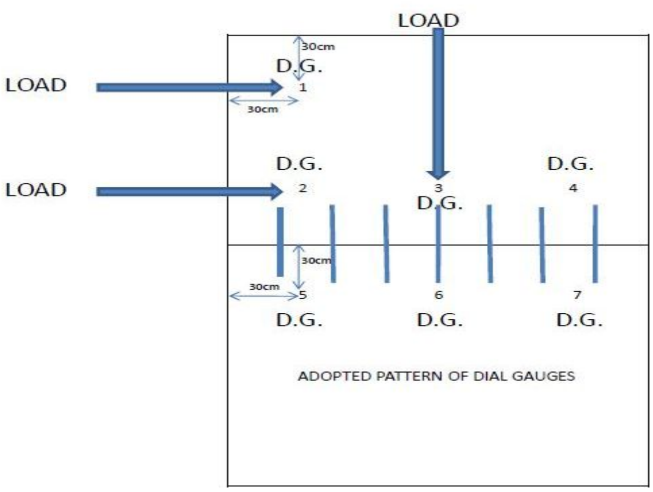

Figure 2 Schematic layout of plate load test conducted in the laboratory

3. RESULTS

3.1. Workability of SCC

It was found that for a given binder content, there is an optimum ratio of CA: FA. If the value of the ratio is higher than the optimum value, then the flow of the mix is reduced apparently. It was supposed that segregation too depends on the ratio of CA: FA, such that at higher ratio, segregation would be higher. But the assumption was wrong because at higher coarse aggregate content only flowability and passability were maximally affected. The possible reason is that the binder material is sufficient for holding either the coarse or fine aggregates, provided the total volume of aggregates remains the same.

For a given total summed volume of coarse aggregates and fine aggregates, more is the content of fine aggregates, more would be the flow. But there is a limitation; the content of fine aggregates could not be increased beyond a certain value. After this value, the segregation of concrete occurs. This is because; the volume of binder was already lower in the concrete mix so as to hold the fine aggregates. This resulted in a lower cohesion & flowability of the mix. In order to increase the flow, if further superplasticizer is added, then the increased effective water content reduced the viscosity of the paste to such an extent that laitance formation takes place.

WMF is acicular and it has high adsorption tendency as well as the tendency to be a part of pore solution at its higher contents. Hence it increases the inter-particle friction by producing friction between cement particles on which it get adsorbed, and it also increases the viscosity of pore solution at its higher contents. Therefore it was observed that with WMF addition the flowability and passability of mix reduced, though up to 20% WMF its rate of reduction was less. Segregation resistance increased with increment in WMF content. With microsilica addition at lower amount 0-5%, the flowability, passability and segregation resistance increased because microsilica has smooth texture and spherical shape, which induces a ball bearing effect between cement particles on whom it get adsorbed. The ball bearing effect does not allow the cement particles to move away though it allows them to roll or slide over each other on account of the sticky nature of microsilica. Khayat & Aitcin (14) also suggest that presence of microsilica affects the properties of fresh concrete by inducing cohesivity and thus reducing the bleeding of concrete. Both of these factors work contradictory as far as shrinkage is concerned; on one hand cohesivity reduces shrinkage, whereas on other the reduced bleeding increases it. The increased cohesivity also requires more slump for a given flow, with respect to a normal concrete. But it has one advantage which is homogeneity, and thus enables good passability and flowability, thereby enabling microsilica admixed concrete as a pumpable concrete. Hence at higher amount of microsilica, the flowability and passability decreased but the segregation resistance increased, because the pore solution between the cement particles get thicker and more viscous due to increased microsilica content. Flyash at all contents improved the flowability and passability of mixes, but it decreased the segregation resistance of self compacting concrete. Table 2 provides the measurements taken while performing the fresh state tests on SCC in the laboratory.

3.2. Load Transfer Efficiency

This test was performed on mixes CWS6 and normal concrete. After obtaining the deflections from the pre-decided gauging locations (as shown in Table 3 & Table 4), efforts have been made to establish equations to find out the load transfer efficiency of the dowel bars provided across the PQC slab for all considered three different cases, under three different loading conditions. This was done by determining the deflections obtained at both ends of the dowel bars.

The locations 2-5 signifies loading side edge bar; 3-6 signifies middle bar, and 4-7 signifies non-loading side edge bar as presented in Figure 2. The ordinate Y in the equation was taken as the deflection on the opposite side of loading, whereas abscissa X was taken as the deflection on the loading side.

Afterwards, a set of deflections was chosen such that the deflections bear uniform difference with respect to each other. Taking these deflections' values as X in the equations, the corresponding Y values were determined. After obtaining the Y values, which are the deflections at the opposite side of loading, the percentage difference between the deflections of the two cases i.e. non-rehabilitated & normal concrete rehabilitated pavement and, non-rehabilitated and fiber reinforced concrete rehabilitated pavement was determined.

The difference in the deflections value so obtained provided a data which could be statistically studied for finding out the reduction in load efficiency of the rehabilitated pavement. The results obtained suggested, that there is 85% probability, that load transfer efficiency is not reduced by more than 30% and 60% for WMF reinforced concrete rehabilitated pavement, and normal concrete rehabilitated pavement respectively. For the same probability, the fiber reinforced rehabilitated pavement shows more load transference than normal concrete rehabilitated pavement. Hence the use of fiber reinforced SCC, improved the load transference of rehabilitated pavement by two times.

4. CONCLUSION

The study confirms that WMF; which belong to micro class of fibers could be used for obtaining self compacting concrete and also increasing the flexural strength of concrete. The fiber introduction in concrete makes it dense by reduction of voids at interfacial transition zone, which is why there is increased load transference from one panel to another in the contraction joint of pavement. All these results clearly represent the possible role of these kinds of microfibers in obtaining shrinkage free high fatigue life rigid pavements

Table 2 Results Obtained from the Workability Test Conducted on SCC in the Fresh State

Mix	Percentage of cementitious materials (C.M.) in Powder				CA:FA	Super plasticizer (ml/cu.m. of mix)	Abram's flow (600-750)(mm)	V Funnel time (6-12) (sec)	V Funnel time after 5 min (+3) (sec)	J Ring diff. (0-10) (mm)	Probering penetration (0-7) (mm)	Super plasticizer (% of C.M.)
	C	F	WMF	SF			Flowability	Flowability	Segregation Resistance	Passability	Segregation Resistance	
C	100	-	-	-	60:40	1227.3	360	17	24	24	2	0.30
CW1	90	-	10	-	55:45	1840.9	560	10	12	21	3	0.45
CW2	80	-	20	-	50:50	1840.9	580	8	10	19	5	0.45
CW3	70	-	30	-	50:50	2454.5	540	12	12	21	4	0.6
CWS1	87.5	-	10	2.5	55:45	1840.9	580	9	11	15	3	0.45
CWS2	85	-	10	5	50:50	1840.9	630	8	10	9	5	0.45
CWS3	82.5	-	10	7.5	50:50	1840.9	620	9	10	10	4	0.45
CWS4	80	-	10	10	50:50	1840.9	605	10	11	13	3	0.45
CWS5	77.5	-	20	2.5	50:50	1840.9	646	7	11	11	5	0.45
CWS6	75	-	20	5	50:50	2454.5	660	7	9	5	7	0.6
CWS7	72.5	-	20	7.5	50:50	2454.5	620	8	11	8	5	0.6
CWS8	70	-	20	10	50:50	2454.5	590	9	14	10	4	0.6
CWS9	67.5	-	30	2.5	50:50	2454.5	570	10	12	14	5	0.6
CWS11	62.5	-	30	7.5	45:55	1840.9	575	9	13	17	2	0.45
CWS12	60	-	30	10	45:55	1840.9	530	13	18	22	2	0.45
CF1	90	10	-	-	55:45	1227.3	570	10	16	15	5	0.3
CF2	80	20	-	-	55:45	1227.3	581	9	17	13	7	0.3
CF3	70	30	-	-	55:45	1227.3	604	7	18	11	9	0.3
CFS1	87.5	10	-	2.5	55:45	1840.9	585	9	16	12	5	0.45
CFS2	85	10	-	5	50:50	1840.9	615	8	14	11	8	0.45
CFS3	82.5	10	-	7.5	50:50	1840.9	600	9	10	15	6	0.45
CFS4	80	10	-	10	50:50	1840.9	573	10	12	18	3	0.45
CFS5	77.5	20	-	2.5	50:50	1840.9	625	7	9	9	7	0.45
CFS6	75	20	-	5	50:50	1840.9	650	6	9	8	9	0.45
CFS7	72.5	20	-	7.5	50:50	1840.9	613	8	9	10	6	0.45
CFS8	70	20	-	10	50:50	1840.9	587	10	11	13	6	0.45
CFS9	67.5	30	-	2.5	50:50	1840.9	633	6	15	11	10	0.45
CFS10	65	30	-	5	50:50	1227.3	663	5	17	8	12	0.3
CFS11	62.5	30	-	7.5	45:55	1227.3	623	7	17	13	9	0.3
CFS12	60	30	-	10	45:55	1227.3	594	8	21	15	7	0.3

Table 3 Deflections for Plate Load Test on Normal Concrete Rehabilitated Pavement

Interior loading	**Deflection in mm at location**						
Load (N)	2	3	4	5	6	7	
112500	0.06	0.3	0.15	-0.07	-0.13	-0.1	
250000	0.3	0.57	0.37	-0.2	-0.3	-0.16	
387500	0.59	0.88	0.66	-0.4	-0.55	-0.21	
Edge loading	**Deflection in mm at location**						
Load (N)	2	3	4	5	6	7	
50000	0.28	0	0	-0.07	0	0	
85000	0.53	-0.06	0	-0.19	-0.02	0	
125000	0.89	-0.13	0	-0.34	-0.07	0	
175000	1.28	-0.23	0	-0.45	-0.19	0	
225000	1.61	-0.26	-0.04	-0.58	-0.28	-0.04	
Corner loading	**Deflection in mm at location**						
Load (N)	1	2	3	4	5	6	7
25000	0.22	-0.01	-0.03	0	-0.01	0	0
50000	0.47	-0.08	-0.07	0.03	-0.02	0	0
70000	0.76	-0.15	-0.1	0.05	-0.03	0.01	0
92500	0.98	-0.23	-0.13	0.09	-0.06	0.03	0.02
117500	1.2	-0.35	-0.16	0.17	-0.09	0.05	0.04
145000	1.48	-0.48	-0.17	0.3	-0.1	0.14	0.06
162500	1.7	-0.59	-0.2	0.39	-0.12	0.19	0.09

Table 4 Deflections for Plate Load Test on FRSCC Rehabilitated Pavement

Interior loading	**Deflection in mm at location**						
Load (N)	2	3	4	5	6	7	
112500	0.04	0.22	0.12	-0.04	-0.07	-0.05	
250000	0.23	0.43	0.3	-0.1	-0.19	-0.09	
387500	0.47	0.7	0.52	-0.2	-0.33	-0.14	
Edge loading	**Deflection in mm at location**						
Load (N)	2	3	4	5	6	7	
50000	0.23	0	0	-0.04	0	0	
85000	0.42	-0.05	0	-0.12	-0.02	0	
125000	0.69	-0.09	0	-0.24	-0.05	0	
175000	1.02	-0.16	0	-0.33	-0.14	0	
225000	1.33	-0.2	-0.02	-0.45	-0.25	-0.03	
Corner loading	**Deflection in mm at location**						
Load (N)	1	2	3	4	5	6	7
25000	0.17	-0.01	0	0	-0.01	0	0
50000	0.38	-0.06	-0.05	0	-0.01	0	0
70000	0.59	-0.12	-0.06	0.02	-0.01	0	0
92500	0.77	-0.18	-0.09	0.07	-0.04	0	0
117500	0.97	-0.27	-0.11	0.13	-0.07	0.02	0.01
145000	1.18	-0.36	-0.14	0.23	-0.08	0.08	0.03
162500	1.39	-0.45	-0.15	0.32	-0.09	0.12	0.06

REFERENCES

[1] Chen, W.F., and Carson, J.L, “Stress-strain properties of random wire reinforced concrete”,ACI Journal, 68 (12), PP. 933-936, 1971.

[2] Kukreja, C.B., and Chawla, S, “Flexural characteristics of steel fiber reinforced concrete”, The Indian Concrete Journal, March, PP. 154-157, 1989.

[3] Khan, T.A.H., Laid, S.M., and Ramakrishna, B,. “Experimental study of SFRC under compression, indirect and pure bending.” Proceedings of the international symposium on fiber reinforced concrete, Madras, India, 1987, 2.39-2.48.

[4] Krishnamoorthy, T.S., and Kumar, B.H. "Influence of steel fibers on the compression and flexural behavior of concrete." Proceedings of the National Seminar on fiber Reinforced Cementitious Products, Roorkee, India, Januray, 1994, 25-32.

[5] Otter, D.E., and Naaman, A.E. "Strain rate effects on the compressive properties of fiber reinforced concrete." Proceedings of the international symposium on fiber reinforced concrete, Madras, India, 1987, 2.225-2.235.

[6] Ramakrishnan, R. "Recent advancement in concrete fiber composites." Proceedings of the International Symposium on Innovative World of Concrete (ICI-IWC-93), Madras, India, 1993, 163-192.

[7] Banthia, N., and Gupta, R., "Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete", J. of Cement and Concrete Research, 2006, 36(7), PP. 1263-1267.

[8] Kovler, K., Sikuler, J., and Bentur, A. "Free and restrained shrinkage of fibre reinforced concrete with low polypropylene fibre content at early age." Fourth Rilem Int. Symp. on Fibre Reinforced Cement and Concrete, International Union of Laboratories and Experts in Construction Materials, Systems and Structures, Sheffield, UK, 1992, 91–101.

[9] Saje, D., Bandelj, B., Sustersic, J., Lopatic, J. and Saje, F., "Shrinkage of polypropylene fiber-reinforced high-performance concrete", Journal of Materials in Civil Engineering, 2011, 23(7), PP. 941–952.

[10] Swamy, R. N., and Stavrides, H., "Influence of fibre reinforcement on restrained shrinkage and cracking", J. of American Concrete Inst., 1979, 76(3), PP.443–460.

[11] Ramakrishnan, R. "Recent advancement in concrete fiber composites." Proceedings of the International Symposium on Innovative World of Concrete (ICI-IWC-93), Madras, India, 1993, 163-192.

[12] Naaman, A. E., and Shah, S. P., "Pull-out mechanism in steel fiber-reinforced concrete", J. Struct. Div., ASCE, 1976 102(8), PP. 1537–1548.

[13] Sharma, S.K., Anupam, A. K., Ransinchung, G.D., and Kumar, P. (2013). "Fiber reinforced cement composites: A Review." Indian Highways, Indian Roads Congress, ISSN 0376-7256, 41 (10), pp. 38-47.

[14] Sharma, S.K., Ransinchung, R.N., and Kumar, P. (2013). "Micro fiber reinforced cement paste and mortar overlays- A review." International Journal of Pavement Research and Technology, Chinese Society of Pavement Engineering, ISSN 1997-1400, 6 (6), pp. 765-772.

[15] Khayat, H.K., and Aitcin, P.C., "Silica fume in concrete- an overview", Flyash, Silica fume, Slag and Natural Pozzolans in Concrete, Ed. V.M. Malhotra, ACI SP-132, Detroit, Michigan, 1992, 2, PP. 835-72.

[16] Langan, B.W.,Weng, K., and Ward, M.A., "Effect of silica fume and Fly ash on heat of hydration of portland cement", Cement and Concrete Research, 2002, 32(7), PP. 1045–1051.

[17] Wittman, F.H., "On the action of capillary pressure", Cement and Concrete Research, 6(1), 1976, PP. 49-56.

[18] Low, N.M.P., and Beaudoin, J. J., "Mechanical properties of high performance cement binders reinforced with Wollastonite micro-fibres", Cement and Concrete Research, 1992, 22(5), PP. 981-989.

[19] Chinnu Mariam Ninan and Dr. M. Nazeer, Investigation on Strength Development of Portland Cement–Slag–Metakaolin Cementitious System. International Journal of Advanced Research in Engineering and Technology (IJARET), 7(5), 2016, pp 28–36.

[20] Shashikant Srivastava, Mohd Arif Ansari, P. K. Mehta and Vikas Srivastava, Flyash as Partial Replacement of Portland Pozzolana Cement in Concrete: An Experimental Investigation. International Journal of Civil Engineering and Technology, 7(6), 2016, pp.207–214